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The Cooling of Rotary Clinker.—IV.*

By W. GILBERT, Wh.Sc., M.Inst.C.E.

APPLICATION OF EXPERIMENTAL RESULTS TO AN INTEGRAL COOLER.

(67) It is now proposed to show how the information gained from the experiments on clinker cooling, previously described, can be applied to analyse the performance of a well-known type of clinker cooler. The type selected is that in which twelve cooling tubes are arranged around the delivery end of the kiln. The kiln in this instance is approximately 400 ft. long, the clinker output is 15½ tons per hour, and the standard coal consumption 24·5 per cent. The calculation starts with an assumed temperature of 2,000 deg. Fah. for the clinker entering the cooling tubes, and proceeds to find how long each cooling tube should be in order to reduce the clinker temperature at exit to 250 deg. F.

(68) A longitudinal section of one tube is shown in *Fig.* 17. The diameter inside the shell plates is 4 ft. and for a length of 6 ft. the tube is lined with firebrick 3½ in. thick. A cross section of the lined portion of the tube is shown in *Fig.* 18, and of the unlined portion in *Fig.* 19. The tube is divided into four stages for calculation purposes, as shown in *Fig.* 17. Stage I is the firebrick-lined portion, and the lengths of Stages II, III, and IV are arranged to give an approximately equal fall of the clinker temperature in each case.

Stage I.

(69) The preliminary data required for calculation purposes are as follows.

(*a*)	Diameter inside lining	3·42 ft.
(*b*)	Length	6·0 ft.
(*c*)	Area in cross section, deducting 9 per cent. charge	8·35 sq. ft.
(*d*)	Clinker per minute	48·2 lb.
(*e*)	Air per minute	125·0 lb.
(*f*)	Air per hour per square foot of cross section, *W*	900·0 lb.

*Concluded from our issues for July and October, 1937, and April, 1938.

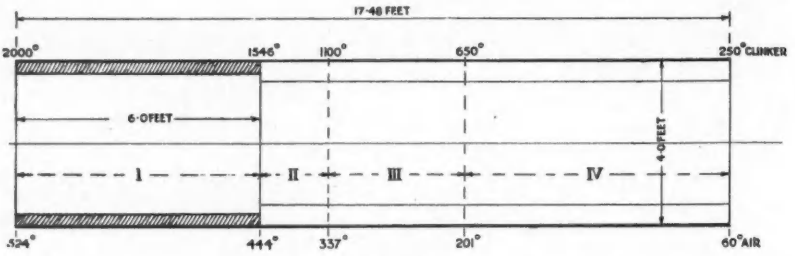

Fig. 17.

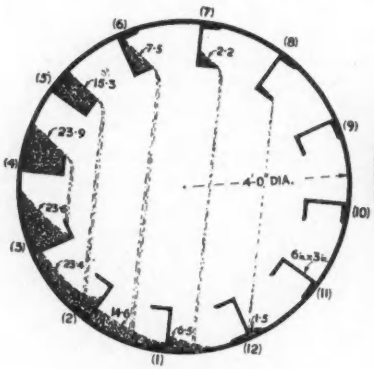

Fig. 19.

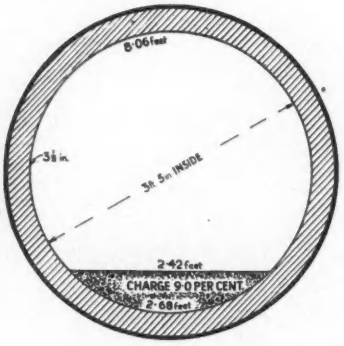

Fig. 18.

(*g*)	Convection constant H_c	2·0
(*h*)	K for firebrick lining as defined in para. (50) ..	8·13
(*i*)	Specific heat of clinker	0·24
(*j*)	Specific heat of air	0·24
(*k*)	Length of upper lining arc *Lua*	8·06 ft.
(*l*)	Length of lower do. *Lla*	2·68 ft.
(*m*)	Length of clinker chord *Lc*	2·42 ft.

The method of calculation, and the values of the emission and absorption factors for clinker and for firebrick lining in various positions, have been previously published (see, for instance, this journal for June, 1933, p. 189).

(70) A statement showing the rate of heat transmission at the centre of the stage is as follows.

HEAT TRANSMISSION IN STAGE I.
(B.T.U. per foot run per minute.)

	Temperature, deg. Fah. (Average for stage).	Black body radiation (in B.T.U. per square foot per minute).
Clinker	1,774	719
Lining	1,589	509
Air	484	—

(*a*) Lining to air : $Td \times Lua \times (H_e \div 60)$ 297
(*b*) Clinker to air : $Td \times Lc \times (H_e \div 60)$ 104
(*c*) Clinker to upper arc : $(719 - 509) \times 0{\cdot}85 \times 0{\cdot}90 \times Lc$ 388
(*d*) Clinker to lower arc : $(719 - 509) \times 0{\cdot}75 \times 0{\cdot}90 \times Lla$ 380
(*e*) Shell radiation loss 472

Td in lines (*a*) and (*b*) denotes temperature difference.

(71) At the beginning of stage I the clinker temperature is 2,000 deg. Fah. Assuming the clinker temperature fall in this stage to be 453 deg. F., the average clinker temperature becomes 1,774 deg. F. as shown.

The lining temperature (inside) is assumed at 1,589 deg. F. If this is correct the quantities in lines (*a*) and (*e*) will equal those in lines (*c*) and (*d*), thus

$$297 + 472 = 388 + 380 \text{ (nearly).}$$

The heat given up by the clinker [see lines (*b*) + (*c*) + (*d*)] in the stage length of 6 ft. must be equal to that liberated per minute by a clinker temperature fall of 453 deg. F., thus

	B.T.U.
$6 \times (104 + 388 + 380)$	= 5,232
$453 \times 48{\cdot}2 \times 0{\cdot}24$	= 5,245

(72) The shell radiation loss in line (*e*) is obtained by equating the heat conducted through the firebrick lining to the heat lost by shell radiation. The shell temperature is found to be 540 deg. F., and the corresponding radiation loss in B.T.U. per square foot per hour is given in Table IV (see this journal for July, 1930, p. 952). The shell area externally, per foot run, is 12·8 sq. ft.

The average air temperature assumed (484 deg. F.) must be in agreement with the heat supplied to the air, since it entered the tube end at 60 deg. F. The relevant figures are shown in *Fig.* 17.

Stages II, III and IV.

(73) The figures required for calculation purposes in the above stages are given in Table X.

TABLE X.—PRELIMINARY DATA FOR STAGES II, III, AND IV.

(*a*) Tube (diameter inside) .. .. 4·0 ft.
(*b*) Charge (per cent.) .. .. 6·70
(*c*) Area of gasway .. .. 11·44 sq. ft.
(*d*) Air per hour per square foot of gasway (*W*) .. 655 lb.
(*e*) Values of H_e : Air and clinker, static .. .. 2·5
(*f*) ,, ,, Air and channels, or shell .. .. 2·0
(*g*) ,, ,, Air and clinker in cascade, average 26·0

Areas for Heat Transmission per foot run.

(*h*) Clinker radiating to shell .. .. 5·66 sq. ft.
(*i*) Clinker radiating to channels .. .. .. 8·52 ,,
(*j*) Channels radiating to shell .. .. 7·00 ,,
(*k*) Air in contact with clinker, static .. .. .. 5·00 ,,
(*l*) Air in contact with clinker in cascade .. .. 3·43 ,,
(*m*) Air in contact with channels .. .. .. 15·50 ,,

(*n*) Air in contact with shell .. .. 6·15 sq. ft.
(*o*) External surface of shell per foot run .. .. 12·80 ,,

Emission and Absorption Factors.

(*p*) Channels or shell .. .. 0·90
(*q*) Clinker .. .. 0·75

The areas in lines (*h*) to (*n*) were measured as carefully as possible from *Fig.* 19.

(74) The calculations for Stage III are given in detail below. In this stage the clinker temperature is reduced from 1,100 deg. F. to 650 deg. F., so that the mean temperature is 875 deg. F. The remaining temperatures have to be assumed in the first instance.

	Temperature, deg. Fah. (Average for stage.)	Black body radiation (B.T.U. per sq. ft. per minute).
Clinker	875	91·8
Channels ..	627	40·3
Shell	460	20·8
Air	269	—

HEAT TRANSMISSION IN STAGE III.

(B.T.U. per foot run per minute.)

(75) (*a*) Clinker radiates to channels: 51·5 × 0·75 × 0·90 × 8·52 .. 296
(*b*) Clinker radiates to shell: 71·0 × 0·75 × 0·90 × 5·66 .. 271
(*c*) Channels radiate to shell: 19·5 × 0·9 × 0·9 × 7·0 111
(*d*) Air takes from clinker in cascade: (606 × 25·6 × 3·43) ÷ 60 886
(*e*) Air takes from clinker in channels and shell: (606 × 2·5 × 5·0) ÷ 60 126
(*f*) Air takes from channels: (358 × 2·0 × 15·5) ÷ 60 185
(*g*) Air takes from shell inside: (191 × 2·0 × 6·15) ÷ 60 .. 39
(*h*) Shell radiation loss: (1,600 × 12·8) ÷ 60 341

An explanation of the calculation in line (*d*) is given in paras. (79) to (83).

(76) If the temperature assumed for the channels is correct the heat entering them must be equal to the heat leaving, or

$$(a) = (c) + (f), \text{ or } 296 = 111 + 185.$$

Similarly for the shell,

$$(b) + (c) = (g) + (h), \text{ or}$$
$$271 + 111 = 39 + 341.$$

The heat taken from the clinker, per foot run per minute, is

	B.T.U.
(1) Heat supplied to air, see lines (*d*), (*e*), (*f*), (*g*)	1,236
(2) Shell radiation, see line (*h*)	341
Total	1,577

In this stage the clinker temperature is assumed to fall 450 deg. F., hence the heat liberated per minute is

$$48·2 \times 450 \times 0·24 = 5,205 \text{ B.T.U.}$$

and the length required for the stage is

$$\frac{5{,}205}{1{,}577} = 3{\cdot}30 \text{ ft.}$$

The air temperature rise in the stage [see para. (69) lines (*e*) and (*j*), and line (1) above] is

$$\frac{1{,}236 \times 3{\cdot}30}{125 \times 0{\cdot}24} = 136 \text{ deg. F.}$$

(77) The calculation results for all stages are given in Table XI.

TABLE XI.—SUMMARY OF HEAT TRANSMISSION IN ONE TUBE OF COOLER.

Line No.			Stage Numbers.			
			I	II	III	IV
1	Clinker temperature (initial) ..	Deg. F.	2,000	1,546	1,100	650
2	Clinker temperature (final)	,,	1,546	1,100	650	250
3	Clinker temperature (fall in stage) ..	,,	454	446	450	400
4	Average air temperature	,,	484	390	269	131
5	Average lining temperature, inside ..	,,	1,589	—	—	—
6	Average channel temperature ..	,,	—	1,061	627	250
7	Average shell temperature	,,	540	820	460	187
		B.T.U.				
8	Air takes from clinker in cascade ..	per min.	—	2,153	2,922	3,333
9	Air takes from clinker (not cascading)	,,	624	324	416	430
10	Air takes from channels	,,	—	581	610	397
11	Air takes from inside lining	,,	1,782	—	—	—
12	Air takes from inside shell	,,	—	147	129	78
13	Shell radiation loss	,,	2,832	1,948	1,125	384
		B.T.U.				
14	Heat given up by clinker in stage ..	per min.	5,252	5,158	5,205	4,627
15	Length required for stage	ft.	6.0	1.67	3.30	6.51
16	Added length of stages	,,	6.0	7.67	10.97	17.48

The heat given up by the clinker in each stage [see line (14)] corresponds to the clinker temperature fall shown in line (3). The quantities in lines (8) to (13) add up to very nearly the same amount. It will be seen that the working length required for the tube is 17·48 ft.

The heat quantities in paras. (70) and (75) are per foot run, hence they have been multiplied by the stage length in each case before entering them in Table XI.

Heat Balance for Cooler.

(78) The heat balance is based on lines (8) to (13) of Table XI, but the hot clinker loss is added. The figures relate to one cooling tube.

	B.T.U. per minute.	Per cent.
(*a*) Air takes from clinker in cascade	8,408	37·5
(*b*) Air takes from channels, shell, lining, and clinker not cascading	5,545	24·7
(*c*) Shell radiation loss	6,289	28·0
(*d*) Hot clinker loss	2,198	9·8
	22,440	100·0

The hot clinker loss is that due to a temperature fall from 250 to 60 deg. F. The cooler efficiency, obtained by adding lines (*a*) and (*b*), is 62·2 per cent.

Clinker in Cascade.

(79) The cascading of the clinker was studied by the aid of a hardwood model 4 in. in diameter inside and 2 in. long, provided with brass channels to scale and with glass end-plates. The material used was standard sand. Any required charge could be inserted, and the cascading action observed by rolling the model very slowly on a level surface. In *Fig.* 19 the distribution of the material due to a charge of 6·7 per cent. is drawn to scale. This charge was sufficient completely to fill each channel when in position (4), the upper surface of the material taking a natural slope of 37½ deg.

(80) The area in cross section of each portion of the charge in square inches is marked on the diagram, so that the quantity cascaded during a movement of each channel from (4) to (5), (5) to (6), (6) to (7), and (7) to (8) can be obtained by subtraction. The quantities are multiplied by the square root of the depth of the fall in each instance, and the average fall for the material cascaded is found to be 2·4 ft. The average time of fall is

$$\sqrt{\frac{2 \times 2{\cdot}4}{32{\cdot}2}} = 0{\cdot}386 \text{ second,}$$

and the mean velocity of fall is

$$\frac{2{\cdot}4}{0{\cdot}386} = 6{\cdot}2 \text{ ft. per second.}$$

(81) MEAN LUMP DIAMETER.—Sieve tests on two representative samples of rotary clinker are given in Table I (July, 1937). From the mesh sizes, or from Table III, a mean diameter can be found for the lumps in each grade, and it appears that sample A has a surface of 3·76 sq. ft. per pound and sample B a surface of 3·91 sq. ft. per pound.

For rotary clinker, the relation between diameter and surface, in accordance with the notation of para. (50), is given by

$$S = \frac{0{\cdot}4674}{D} \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (6)$$

If all the clinker lumps are assumed to be 0·12 in. in diameter, the surface in square feet per pound by formula (6) is 3·89, hence this diameter and surface are taken as representative for the clinker in cascade.

(82) SURFACE IN CASCADE.—Assuming the clinker carried by the channels to weigh 92 lb. per cubic foot, the load per channel, per foot run, in position (4) is

$$\frac{23{\cdot}9}{144} \times 92 = 15{\cdot}25 \text{ lb.}$$

Hence the weight cascaded per minute (at 1 revolution per minute) is

$$12 \times 15{\cdot}25 = 183 \text{ lb.}$$

The period in cascade is only 0·386 second so that the average surface in cascade is

$$183 \times 3{\cdot}89 \times \frac{0{\cdot}386}{60} = 4{\cdot}58 \text{ sq. ft. per foot run.}$$

(83) For various reasons, such as (*a*) shielding, (*b*) the unequal rate of cooling due to the variation in the lump diameter, and (*c*) a small fall in the lump surface temperature during cascade, only 75 per cent. of the surface, or 3·43 sq. ft., is used for calculation purposes.

(84) VALUE OF H_c FOR CLINKER IN CASCADE.—The value of Wa to insert in formula (5) is obtained by compounding the velocity of the air through the tube with the average velocity of fall in cascade (see *Fig.* 20). Put in terms of air weight in lb. per square foot of cross section per hour, we have for the air velocity through the tube $W = 655$ [see Table X, line (*d*)].

The value of W_f, which corresponds to the velocity of fall, is given by

$$W_f = \frac{3{,}600\, v}{Vp} \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (7)$$

where v = mean velocity of fall in feet per second, and

Vp = air volume in cubic feet per pound.

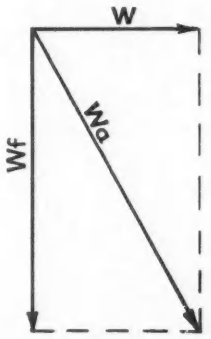

Fig. 20.

(85) In stage III, for instance, the average air temperature is 269 deg. F.; hence Vp, as taken from suitable Tables, is 18·4, so that

$$W_f = \frac{3{,}600 \times 6{\cdot}2}{18{\cdot}4} = 1{,}210$$

and $$Wa = \sqrt{1{,}210^2 + 655^2} = 1{,}376.$$

Since the representative value of D is 0·12 in. we have, for stage III, by formula (5)

$$H_c = \frac{0{\cdot}328 \times \sqrt{1{,}376}}{0{\cdot}12^{0.35}} = 25{\cdot}6$$

The calculation made in para. (75) line (*d*) will now be understood.

GENERAL CONCLUSIONS.

(86) It should be pointed out that the kiln output and the cooler dimensions correspond to general practice, but the temperature of 2,000 deg. Fah. at which the clinker enters the cooler has been assumed. This type of cooler is not well

adapted to take in clinker at a higher temperature, hence the kiln end must act to some extent as an inefficient cooler.

(87) The heat balance in para. (78) shows that the cooler efficiency is only 62·2 per cent. The radiation loss is large because the shell surface is relatively large, and the hot clinker loss is considerable because the cooler is unable to reduce the clinker temperature below 250 deg. Fah. in the length allowed.

(88) The cooler shell surface can be reduced if the rate of heat transfer is increased, and a study of lines (8) to (12) in Table XI show that the only method of doing so is to add to the clinker surface in cascade. The lifter capacity, and the average depth and time of fall (for the same tube diameter), might be considerably increased.

(89) It would, however, be more effective to add to the surface in cascade by increasing the cooler speed, and this could be done by disconnecting it from the kiln. A short and efficient cooler, which would take in clinker at 2,200 deg. Fah. and reject it at 120 deg. Fah., could be thus obtained. The saving in coal due to an improved type of cooler might well be one ton per 100 tons of clinker.

Government Cement Purchases in the United States.

DIFFICULTIES have arisen between the Government and the cement trade in the United States as a result of a new system of obtaining quotations for cement to be used in Federal Government works. Under the new arrangement the Treasury Department is attempting to centralise the purchase of cement throughout the country, and quotations were required for cement at the mills for a period of four months. The quotations were to apply to cement required by Government contractors, as well as by departments for direct labour work. Prices were to be per barrel, no minimum quantity was mentioned, and the Government did not guarantee to buy any cement at all during the four-months' period; the Government was, in fact, to have an option to purchase at a fixed price.

Several of the more important cement makers have declined to submit quotations on this basis. They claim that prices at the works would, if applied to all contractors undertaking Government work, interfere with the existing arrangements with merchants. They also state that the acceptance of the lowest price at the factories would destroy competition, and give each factory a monopoly in its own area. In those cases where quotations were asked for at points where the local cement makers have not sent in a quotation, the quotations of manufacturers in other districts have been accepted at an inclusive price, including delivery. The timber, paint, brick, and other industries supplying building materials are protesting to the Government, expressing the hope that this method of purchasing materials will not be applied to their industries.

Design and Operation of Modern Lime Works.—XII.*

By N. V. S. KNIBBS, D.Sc.

STORAGE, SORTING, CRUSHING, GRINDING AND GRADING LIME.

Storage.

Lime is a difficult substance to store economically. On the one hand exposure to air leads to air slaking, and on the other hand the handling entailed in storage in air-tight bunkers almost inevitably causes mechanical breakage. Because in the past lime has been demanded in large lumps the general practice has been to avoid prolonged storage. This entails operating the kilns to suit the demand, which, in turn, influences the type of plant used. Large units are difficult to operate economically unless they can be kept going constantly at a large enough output, and this is possible with a fluctuating demand only if the lime produced can be stored. The type of kiln favoured has also been influenced by the storage difficulty, which has had a great deal to do with the persistence to the present time of such obsolete and inefficient types as the flare kiln. It has also to some extent retarded the adoption of gas firing because a gas-fired kiln, for the sake of economy, should be operated within narrower limits of output than are necessary on a mixed-feed kiln.

With the general use of hydrated lime, and the extended use of ground lime, the situation has changed because hydrated lime can be stored indefinitely and ground lime can be economically stored in closed silos. At the same time the illogical demand for lime in large lumps is slowly disappearing and with it the necessity for avoiding the breaking up of the lime in handling. Lime produced in rotary kilns or in any other kiln which burns it in small pieces is also well adapted to mechanical handling and storage in closed silos.

In plants where it is necessary to store lump lime without undue breakage shallow or sloping bunkers may be used, but a frequent practice is to use rail wagons to accommodate the day-to-day fluctuation. For small lime, or lumps where breakage is immaterial, steel or concrete silos are used with outlet doors of a size to accommodate the size of lime stored. If the lime is to be kept for any considerable time the outlet door should be nearly air-tight, otherwise air leaking through the door will slake the adjoining lime, causing it to swell and to "hang up" there and prevent the normal discharge of the contents.

Sorting and Separating Ashes.

The lime drawn from a kiln burning lump limestone consists of lumps and smalls and, from a mixed-feed kiln, ashes. On mixed-feed kilns a frequent practice is to incorporate a screen in the bottom of the kiln so that the lime drawn passes over the screen and is freed from the bulk of the fine lime and ashes. The same practice may be adopted in gas-fired kilns, but it is unusual.

* Previous articles in this series appeared in our issues for January, February, March, April, May, August, September, October, November and December, 1937, and January, March and April, 1938.

In either case it is nearly always necessary to sort the lime drawn, and for efficient sorting it is desirable that it should be spread out so as to be easily visible and accessible. The fine material may conveniently be removed at the same time. Methods of sorting vary from the simple procedure of drawing the lime directly into a wagon in small amounts and there sorting out the inferior lumps, to the method in which the lime is mechanically spread out on a slowly or

Fig. 47.—Sorting Belt.

intermittently travelling belt which passes the sorters. In many plants the lime is spread on the floor for sorting, but this involves extra handling.

Fig. 47 shows a picking belt of the intermittent type operated by push-button control. It is started, run until a layer of lime covers the whole length, stopped, and the lime sorted, and then restarted to convey the picked lime to bunkers and to spread a fresh layer on the belt. Kilns drawn continuously are best served by a picking belt of the same kind operated slowly but continuously.

Hand sorting is practicable only when the lime is made in relatively large lumps. When small lime is produced, as in a rotary kiln or in a shaft kiln

specially designed to burn small material, the number of pieces to be inspected per ton of lime is so great that hand sorting would be extremely costly if it were practicable, which it is not. The method used for separating good coal from shale and other impurities is adaptable also to the separation of properly burnt lime from both overburnt and underburnt lime, and no doubt some such method will in future be used for the purpose..

Feeding.

For efficient crushing, pulverising, or grinding it is important that the mill should be fed at a constant rate, and this is attainable economically only by the

FIG.198

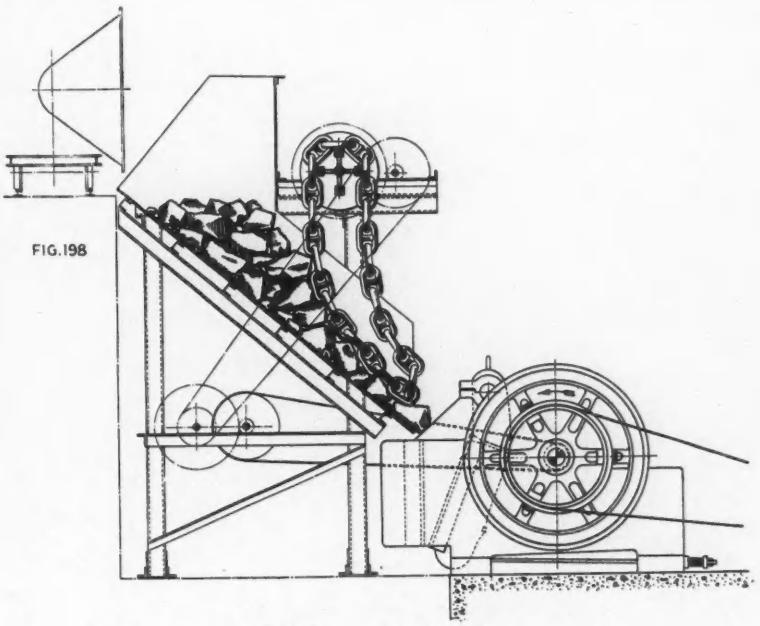

Fig. 48.—Chain Feeder.

use of a mechanical feeding device. Lime in large pieces, as it comes from a vertical kiln, is not very well adapted to mechanical feeding at the slow rate that is necessary, but there are several types of feeder that can be used. The far end of the picking belt shown in *Fig.* 47 is, in effect, a feeder of the apron type, and the continuous discharging mechanisms for kilns, previously discussed,[1] are all lime feeders. A chain feeder, as shown in *Fig.* 48, where the rate of feed is controlled by heavy chains which impede the free passage of the material down a chute, is much used for lump material. The chains move with the material, and their speed controls the rate of feed. A sloped chute with a to-and-fro

[1] "Cement and Lime Manufacture," March, 1937, pp. 81 and 82.

movement set under the bunker discharge opening at an angle substantially flatter than the angle of repose of the material, is another type that may be used with large pieces. For material of smaller size and for powder there are other feeders available such as the Archimedean screw feeder (a screw in a cylindrical housing) and the rotary table feeder, which is a circular table slowly rotating under the feed opening and from which the material is scraped by an adjustable plough.

At best all these feeding devices deliver a constant volume of material and consequently the weight fed will vary with density, which may change through variation in the grading. Feeders are available which weigh the material and deliver it by weight, but they are costly and are seldom justified for small rates

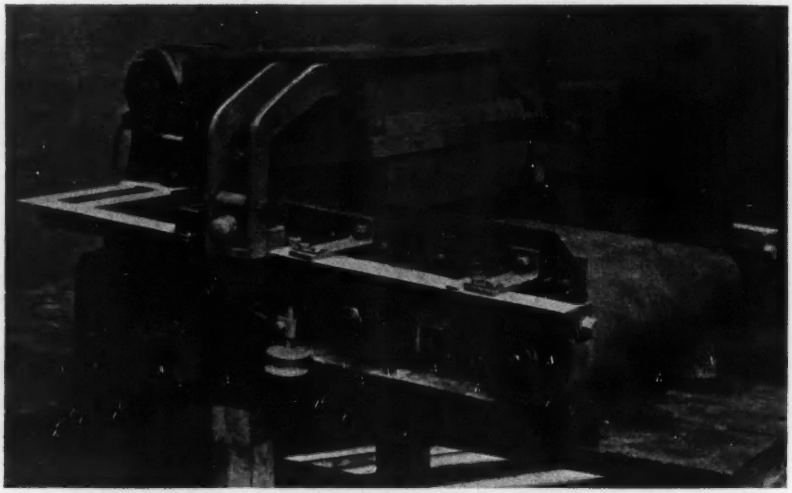

Fig. 49.—Constant Weight Feeder.

of feed. There is available, however, a " constant weight " feeder (*Fig.* 49) of an intermediate type. It is an apron feeder in which the apron full of material constitutes one arm of a balance and any increase in weight, causing it to tip down, operates through a lever and partially closes the gate controlling the depth of the material on the apron. A decrease of weight opens the gate. By recording the revolutions of the pulley carrying the belt or apron the total weight fed over a period may be approximately computed.

Crushing.

Properly burnt lime is ordinarily a soft material easy to crush and causing very little wear and tear of crushing machinery. On the other hand, if it is overburnt it may be extremely tough and fairly hard. Underburnt lime contains a core of limestone which is about as hard as the unheated stone but generally

somewhat more brittle. Well-burnt lime therefore requires only light crushing machinery, but, depending on how much underburnt and overburnt lime it contains, the crushers must have a margin of safety and be capable of dealing with the harder material. On most lime plants the main difficulty in providing suitable crushing plant is due to the size of the lumps of lime and to the output of crushed lime required generally being comparatively small. Any crusher capable of taking full-size lumps of lime is necessarily so large that its output may be many times the output actually required, and the capital cost is corre-

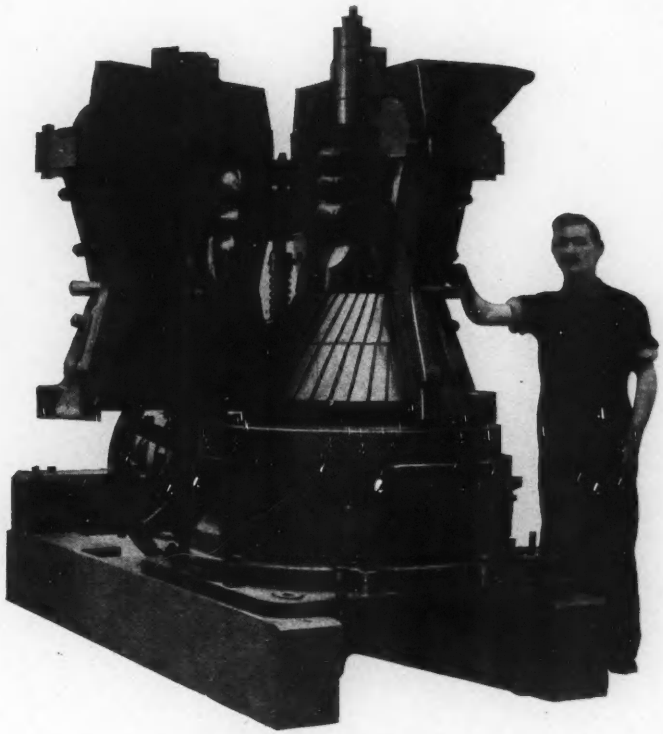

Fig. 50.—Large Rotary Crusher.

spondingly great. Crushers are generally required to break the lime down to a size suitable for feeding either to fine grinding units or to hydrating plant. This generally involves crushing to 1 in. or less so that the reduction ratio is at least six to one and usually much more. The jaw crusher, which is the cheapest machine capable of taking these large lumps, has a small ratio of reduction and is of limited use only in the lime industry. A type that has a large ratio of

reduction and which is used to a considerable extent for crushing lime is the rotary crusher shown in *Fig.* 50. It must not be confused with a gyratory crusher, which has a much lower reduction ratio but which is suited to hard rocks, including limestone. With hard materials the wear on the rotary crusher is excessive, and on tough materials, as for instance on very hard-burnt lime, there is too great a tendency to choking, but on ordinary lime the results are satisfactory, the reduction ratio high, and the power consumption low. Crushing rolls are satisfactory on lime but their reduction ratio is not great.

Pulverising.

Lime is a suitable material for reduction by pulverising machines which crush by impact. Nevertheless, if the lime contains any considerable quantity of unburnt core or is excessively hard burnt, or if it is highly siliceous and consequently hard, the high-speed fixed-arm type of disintegrator is unsuitable

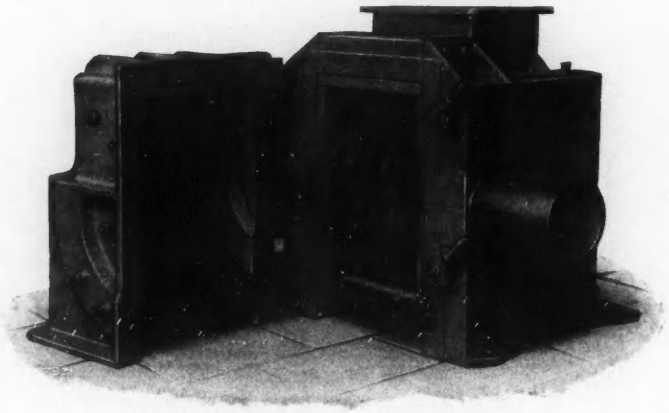

Fig. 51.—Hinged Hammer Mill.

because of the excessive wear. Impact machines in general have a high reduction ratio. Depending on their size, they will take large lumps of lime and produce a fine product in one operation. A uniform lightly-burnt lime, and especially one made from chalk, may be finely ground from full-size kiln lumps to smaller than a 20-mesh product with a reasonable power consumption and without undue wear. Ordinary run-of-kiln lime is better dealt with in a hinged-hammer pulveriser, as shown in *Fig.* 51, which will have the same capacity for taking large lumps but which will not economically grind as finely as the fixed-arm type of disintegrator. A hinged-hammer pulveriser of the larger sizes, dealing with full-size kiln lime, will economically reduce lime to pass a 5-mesh sieve. This type of mill is also suited to pulverising limestone. The smaller sizes of both types of pulveriser will economically reduce to a finer grading.

Both types of machine are sometimes operated in closed circuit with separating plant, but unless the mill itself is air swept this type of operation is seldom economical. Air-swept impact pulverisers are largely used in the lime industry especially for hydrated lime.

The performance of an impact pulveriser depends on its speed, and its efficiency increases with increased speed, but so also does wear and tear. *Fig.* 52

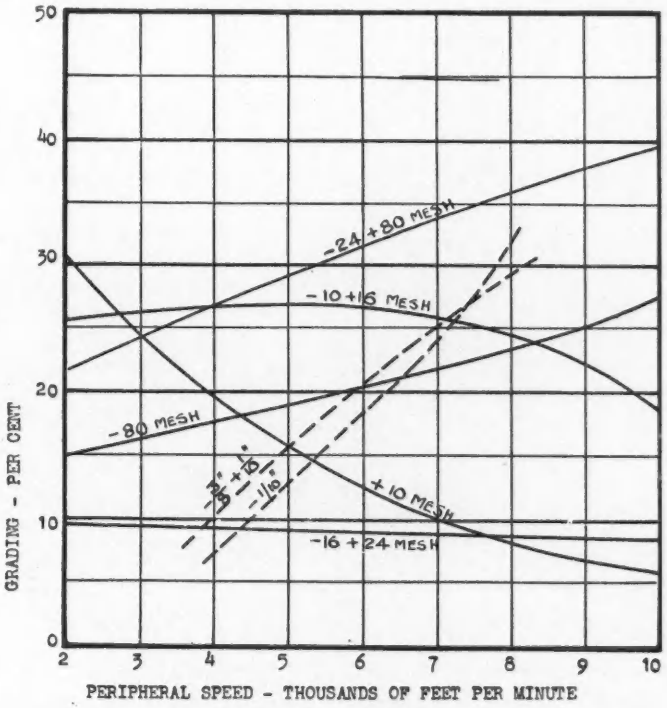

Fig. 52.—Variation of Grading with Speed—Swing Sledge Mill.

Full lines—Mill with ¼-in. grates. Broken lines—Mill with 1-in. grates. Both grinding limestone.

shows the effect on fineness of speed variation in a small swing-sledge mill pulverising limestone.

Fine Grinding.

Air-swept impact pulverisers are used to some extent for fine grinding of burnt lime, but the more usual machines are either roller mills (*Fig.* 53) or tube mills. The difficulty in the fine grinding of lime lies in the cushioning effect of the ground material. The softness of the lime makes it a cheap material to

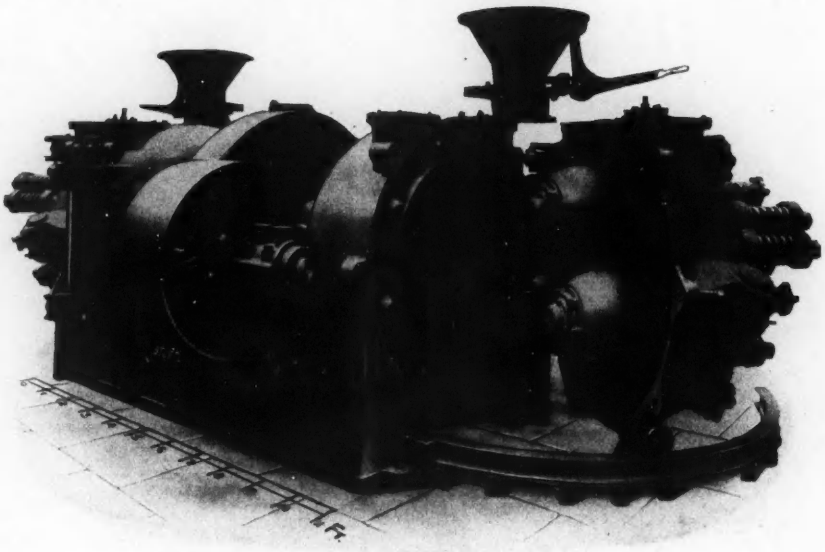

Fig. 53.—Ring-Roll Mill

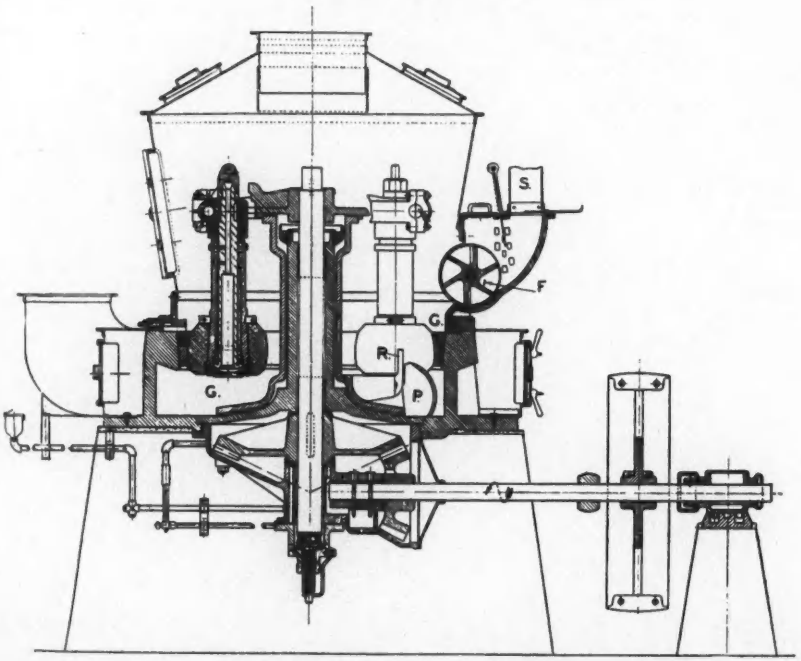

Fig. 54.—Roller Mill—Air-Swept.

pulverise by impact but greatly reduces the effectiveness of tube and roller mills unless the ground material is rapidly removed, and consequently roller and tube mills for lime grinding should be air swept. Tube mills particularly have a low efficiency in the fine grinding of lime unless they are air swept, and it is of historic interest that the first air swept tube mill used commercially operated on lime. A roller mill adapted to air sweeping in closed circuit is shown in *Fig.* 54. The

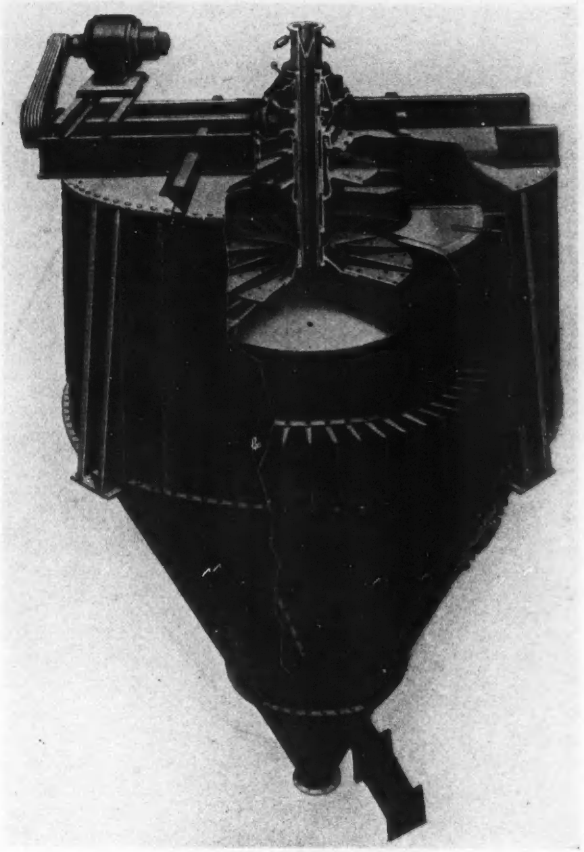

Fig. 55.—Air Separator.

quantity of finely-ground burnt lime used is relatively small, as for most purposes a screened impact mill product is sufficiently fine. The milling of hydrate is discussed later.

Screening.

Inclined screens vibrated mechanically or electrically are used for separating lime down to about 50 mesh. For finer separation they are generally inefficient

owing to the propensity of ground lime to blind the screen. The efficiency is rather low on grades finer than about 30 mesh unless it happens to be a free screening product with a very small proportion of a grade just coarser than the screen.

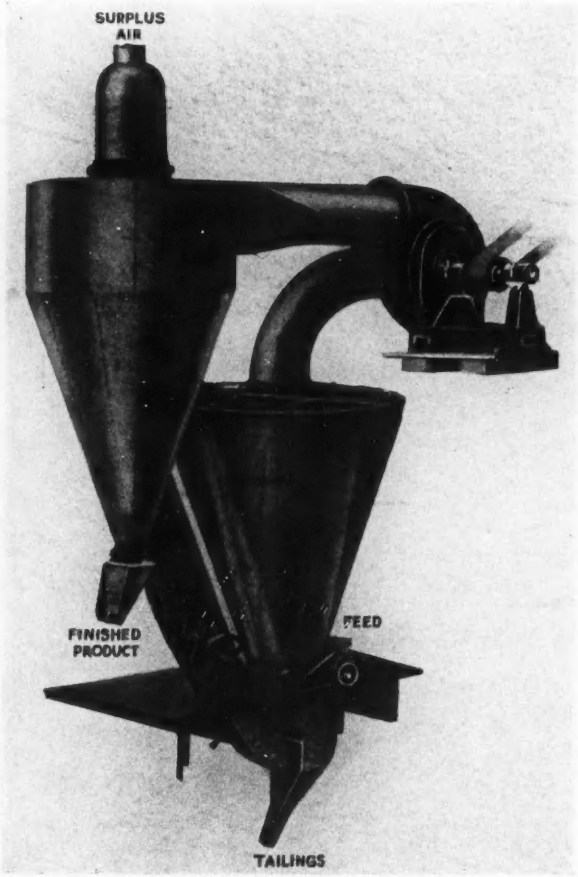

Fig. 56.—Air Separating Unit.

Hydrated lime screens freely when fresh and hot but it is (or should be) accompanied by steam which condenses on the screening surface and elsewhere and causes blinding and choking troubles. Hydrated lime is consequently seldom screened in modern plant.

Air Separators.

Air separators are of two types. One, which is often called a " mechanical " separator, is a self-contained unit into which the material is fed at the top and which delivers two products—" fines " and " tailings "—from two spouts at the bottom. There are many makes of mechanical separators but in principle they are all the same (see *Fig.* 55). The material passes down on to a horizontal

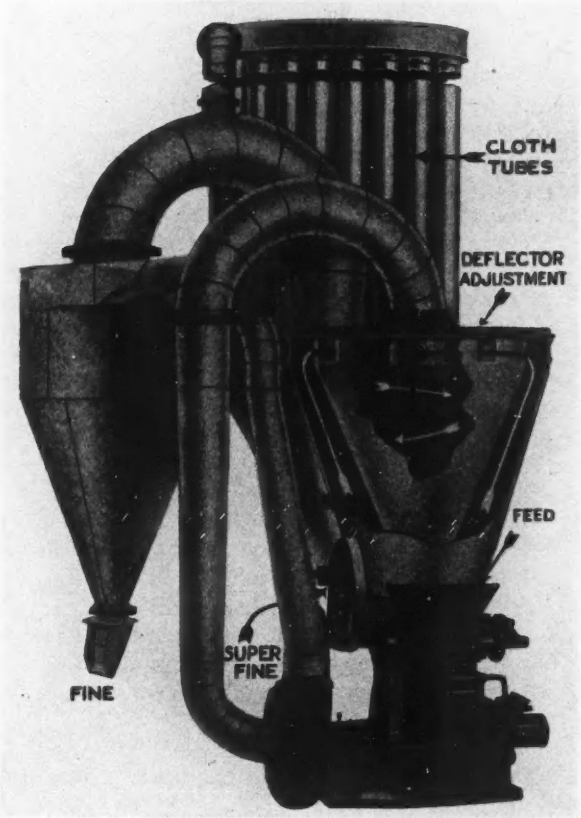

Fig. 57.—Pulveriser, Air Selector, Cyclone, Fan and Filter.

rotating table from which it is thrown out by centrifugal force. A horizontal fan wheel is mounted above the table on the same shaft and this fan draws air up past the powder thrown out from the table, carrying with it the finer portion of the material. The coarser material, or tailings, not caught up by the air

falls down through an inner cone and emerges at the side spout near the bottom. The air carrying the finer material is blown by the fan into the outer casing where, the velocity being less, the greater part of the fine powder separates and falls out through the central spout. The air recirculates into the inner chamber through the vanes shown in the illustration. In a modified form the material, after being spread and swept by the air, meets a cone which deflects it back on to another lower rotary table where it is spread again and swept by the ascending air before the latter reaches the first table, and this may be repeated five times or more.

Mechanical separators are made in sizes up to 18 ft. diameter and with capacities up to 50 tons or more an hour. When well designed and substantially built they operate for long periods without attention and they are most reliable in their results. The power consumption per ton of material treated is small, though more than that of a screen. The separation attained can never be theoretically perfect (for example, if the fines must all pass a 50-mesh sieve the tailings will always contain some which will pass a 50-mesh sieve) but, depending on the grading and physical nature of the material treated, it may be sufficiently complete for practical purposes. Where complete separation is required a combination of two separators, as explained later, is effective with relatively little increased power consumption.

The second type of air separator (*Figs.* 56 and 57) is that in which the material is fed into an air current set up by a fan of conventional type, the dust-laden air passing directly into a " classifier " or " separator " (which in *Fig.* 57 has the side removed to show the interior) where the coarse particles are separated and returned to the bottom and the fines carried on with the air to be separated at a cyclone separator, the air returning to the base of the classifier. Since air is drawn in with the feed there must be an air vent at one point, and in *Fig.* 57 this is shown attached to a cloth tubular filter.

Fig. 56 shows the simple form of this system. Its advantages over the single mechanical separator are that it effects a more complete separation and that, if necessary, the fine material may be delivered at a short distance or height by lengthening the duct between the classifier and the cyclone. Its disadvantages are its much greater power requirement and its greater maintenance cost if the material is at all abrasive.

This type of separator is well adapted to combination with impact pulverising, as shown in *Fig.* 57. Here the classifier continually returns the oversize material to the mill until it is fine enough to pass on to the cyclone. This combination may also be provided with a " throw-out " gate where the coarsest material is eliminated by being projected against a strong current of air.

The author is indebted to the following firms for the illustrations: Priest Furnaces, Ltd., Fig. 47; Ross Engineers, Ltd., Fig. 48; International Combustion, Ltd., Figs. 49, 54, 55, 56, 57; Sturtevant Engineering Co., Ltd., Figs. 50, 51, 53.

(*To be continued.*)

Soundness Test for Lime.

THE following note is taken from the *Technical News Bulletin* (No. 251, March, 1938) of the United States National Bureau of Standards. A test for "pitting and popping" of limes used in the finishing coat of plaster was devised by D. L. Bishop and published in "Rock Products" (July 18, 1931). This test consists of steaming specimens in an autoclave for two hours. The specimens of the finishing coat are prepared by mixing 2 volumes of lime putty with 1 volume of unretarded calcined gypsum and sufficient water to form a paste, and then spreading a layer, $\frac{1}{16}$ in. to $\frac{1}{8}$ in. thick on a 4-in. by 4-in. glass plate. The specimens are then set aside for two hours to allow the gypsum to set, after which the specimens are placed on a rock in an autoclave and steamed for two hours at a pressure of 120 lb. per square inch. Unsoundness as applied to finishing limes is shown by the development of crater-like holes known as "pits" or "pops." It is essential, in conducting the test, that prior to steaming the specimens be so stored as to prevent evaporation of the water, because otherwise a disintegration or cracking of the specimens may occur which bears no relation to the development of unsoundness on the wall. The soundness of the calcined gypsum used in this test should be assured by testing with a lime putty that has been previously steamed in the autoclave for two hours at 120 lb. pressure.

This test, essentially that described in Tentative Methods of Physical Test for Limestone, Quicklime, and Hydrated Lime (American Society for Testing Materials Designation C 110–34T) is particularly advantageous as a works control method because (if a soaking period is dispensed with) the test can be completed in about three hours. The test is also more reliable than the longer one given in the standard specification.

Very good correlation was originally obtained between the autoclave test and the actual development of pits and pops, but because of the continued interest in the method, more panels have been prepared to check further the reliability of the method. Nineteen panels have been prepared and are now about one year old. Of these limes, 11 of them were shown to be unsound by the test and have developed unsoundness (pitting) in the panels upon ageing in the laboratory. Two of the limes that were unsound in the test have not yet developed unsoundness in the panels. Five limes that were sound under test have remained sound. One lime was sound under test, but has developed unsoundness. The status of all the panels previously reported in "Rock Products" (July 18, 1931) has remained the same with the exception of one panel (No. 22) which, although sound under the test, has developed one pop (over an area of $1\frac{1}{4}$ sq. ft.). Out of the total of 52 panels tested, 34 limes were unsound under test and developed unsoundness in the panels. Twelve were sound under test and have remained sound in the walls. Three limes were unsound under test and have remained sound, whereas three were sound in the test but have developed unsoundness in the walls.

It should not be construed that the limes on the market will be unsound under the test in the same proportion as they have in the limes here reported.

High-Alumina Cement in Japan.

By SHOICHIRO NAGAI.

ALUMINOUS cement has not hitherto been manufactured in Japan owing to the lack of raw materials containing large amounts of alumina as bauxite. Recently, however, it became possible to obtain suitable raw material of large alumina content from Manchoukuo and North China, and the Osaka Yogyo Cement Co. has now started the manufacture of high-alumina cement by using this high-aluminous clay. The author has tested several samples of this Japanese high-alumina cement; the following are the principal results :—

The chemical compositions were SiO_2, about 6 to 8 per cent.; Fe_2O_3, about 1 to 3 per cent.; CaO, about 36 to 38 per cent. and Al_2O_3, about 50 to 55 per cent. The content of Fe_2O_3 is very small, owing to the use of electric furnaces and the low content of Fe_2O_3 in the raw material.

The specific gravity is low (2.93 to 2.98) and the time of setting is a little too quick owing to the small content of Fe_2O_3 and the large content of Al_2O_3.

Strength tests were made by (1) the ordinary non-plastic (earth-wet or moist-earth) mortar and (2) special plastic mortar, and gave satisfactory results.

The relation between strength and curing temperatures (20 deg. C., 50 deg. C., and 75 deg. C.) was tested, and it was found that the strength was considerably reduced by high temperature curing.

The relation between strength or time of setting and the fineness of the cement was studied, and it was found that from 3.5 to 10 per cent. residue on a sieve with 4,900 meshes per square centimetre was most suitable.

Recent Patents Relating to Cement.

Concretes and Mortars.

474,085. R. Barker, G. Brier, R. Fox, L. V. Fox, E. Jukes and A. M. Smith. May 1, 1936.

A cement mortar or concrete comprises a mixture of Portland cement, granulated or powdered slate, and granulated or powdered burnt blue bind or shale, gauged with the supernatant liquid obtained by mixing soap and an aqueous suspension of lime and allowing to settle. Powdered granite may be incorporated in the mixture. Blocks and the like which are moulded from the mixture may be faced with glass by moulding the mixture on to a glass sheet, preferably with a roughened surface, or by covering the outer surface of the block in the mould with glass sand and pouring thereon a layer of molten glass.

Cement and Concrete.

475,820. H. S. Freeman, W. Perry and G. J. H. Jeffs. June 2, 1936.

The formation of ice in cement or concrete is prevented by incorporating therein an aqueous solution of sodium or magnesium chloride and sodium or potassium silicate, or the product obtained by evaporating the solution to dryness. The solution may comprise sodium or magnesium chloride 4 parts, potassium or sodium silicate 1 part, and water 15 parts; about 20 per cent. of this solution may be incorporated in the cement or concrete mix, or 5 per cent. of the product obtained by evaporating the solution to dryness may be incorporated in the mix or premixed with the cement.

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